XLVIII. *Electrical Experiments, to explain how far the Phenomena of the Electrophorus may be accounted for by Dr.* Franklin's *Theory of poſitive and negative Electricity; being the annual Lecture inſtituted by the Will of* Henry Baker, *Eſq. F. R. S. By* John Ingenhouſz, *M. D. F. R. S.*

Read June 4, 1778.

HAVING had the honour of being appointed by the Preſident and Council of the Royal Society to read the annual diſſertation on ſome philoſophical ſubject, inſtituted by our worthy member the late Mr. BAKER, I have endeavoured to purſue ſome electrical experiments, to explain how far the *Electrophorus perpetuus* may be accounted for upon the almoſt generally received theory of Dr. FRANKLIN of poſitive and negative electricity.

THIS electrical inſtrument conſiſts of two different pieces; *viz.* 1. a metallic body, in the form of a plate, or any other convenient figure, furniſhed with an inſulating handle, to be uſed for lifting it up; and 2. a flat non-conducting ſubſtance, ſuch as glaſs, reſin, or ſome other non-conducting matter, upon which the ſaid metal plate is placed.

This machine, invented by Mr. VOLTA, a learned gentleman of Como, is certainly a valuable acquiſition to the Electrical apparatus. Once excited, it is for a long while ready to afford electricity enough for all experiments which do not require a very great force; and it has the advantage of not being ſo much affected by damp weather as the common machines with glaſs globes, cylinders, diſk, &c. It is very eaſily put in action by a ſlight friction with a dry hand, a piece of leather, a rough ſkin of a hare, a cat, or ſome other animal. It is as eaſy to excite with this machine a negative as a poſitive electricity. It has the advantage of being capable at almoſt all times of affording at pleaſure ſuch a force of electricity as is wanted, even to ſuch a degree, that the metal plate is no longer able to contain all the electric fluid communicated to it; but throws it out every way, either upon the metal upon which the reſinous cake is uſually fixed, or into the air: and this increaſe of electrical power is obtained by the eaſieſt means; for inſtance, by charging with the Electrophore a coated phial, and placing it afterwards upon the reſinous cake itſelf, or upon the metal plate placed upon the reſinous cake (provided the metal plate be leſs in circumference than the reſinous cake, and no metallic communication exiſt between the metal plate and that metal upon which the cake is faſtened). If the knob of the phial, thus placed, be touched by the finger, and then taken away, holding it by the knob, the force of the electrophore is found to be remarkably increaſed.

But a more pleaſing way of increaſing the electrical force of this inſtrument is by transferring alternately the metal plate from one reſinous cake to another, and touching it after it is placed upon the cakes. By this method both cakes acquire continually more and more electricity; ſo that in a ſhort time, by this alternate tranſlation, the metal plate returns from either cake quite overcharged; and thus Leyden phials may be charged by it very ſtrongly, and even ſo as to break them. It is very remarkable, that by this method the metal plate returns from one cake in a poſitive, and from the other in a negative ſtate.

This manner of increaſing the two electricities was found out by my learned friend Dr. KLINKOCH, profeſſor in the Univerſity of Prague, ſoon after I had given him a deſcription of this new inſtrument, which I had received from his Royal Highneſs the Arch-duke FERDINAND a very little while after Mr. VOLTA had invented it.

It is true, that Father BECCARIA had a long while ago excited an electricity, almoſt perpetual, by two panes of glaſs, one placed upon the other, each having but one metal coating, and joined together ſo that no metal was placed between the two glaſſes. Theſe two glaſſes being applied to a prime conductor of an electrical machine, ſo as to receive a charge in the ſame way as one glaſs coated on both ſides is to be charged, afford numberleſs ſparks from both coatings, after the two glaſſes have been diſcharged in the common way, by making a communication between the two coatings.

In order to produce theſe ſparks, the two glaſſes muſt be ſeparated from one another, ſo as to avoid touching the coatings in the moment of ſeparation. Each of the coatings will give a ſpark, which may be repeated after having replaced the two glaſſes one upon another. After the two glaſſes have been thus joined again, and touched after their conjunction, another ſpark is obtained from both after their ſeparation; and theſe ſparks may be thus repeated almoſt *ad infinitum*; ſo that theſe two glaſſes, once excited, ſeem to be an unexhauſted ſource of electrical ſparks. Father BECCARIA calls this experiment *electricitas vindex*. Whether this denomination be a proper one to convey ſome idea of what is underſtood by it, I will not now undertake to determine.

The ſame Father BECCARIA had alſo found, that the coating of a glaſs, after being diſcharged, was able to give new ſigns of electricity, when taken off by means of ſilk ſtrings.

Some other experiments were made many years ago by Mr. CIGNA of Turin, and by ſome other electricians, which have a great deal of ſimilarity with the electrophore.

But as the inventors of theſe experiments did not adapt them as an electrical machine, they do not diminiſh at all, in my opinion, the honour which Mr. VOLTA deſerves, for having enriched the electrical apparatus with a very ſimple and handy machine, continually ready to excite as ſtrong an electricity as is requiſite for the moſt ordinary purpoſe.

The novelty and ſimplicity of the machine could not but ſtrike every electrician; I cannot expreſs how much I was pleaſed with the firſt ſight of it, and with what eagerneſs I ſet about endeavouring to underſtand the nature of it. I analyzed it in various ways: I compared it with Father BECCARIA's *electricitas vindex*, with an ordinary coated glaſs, and coated reſinous electrics.

Some electricians, puzzled with the ſtrange phenomena which it affords, thought it over-turned entirely the almoſt univerſally received theory of Dr. FRANKLIN, and that it could not be underſtood but by eſtabliſhing new principles.

After conſidering the matter maturely I thought, that theſe phenomena, though at firſt ſight extraordinary, could be explained by the ſame principles which were already received by almoſt every philoſopher.

But before I proceed to my intended explanation of the moſt obvious phenomena of the electrophorus, I muſt beg leave to ſet down ſome conſtant laws, which nature obſerves in the various motions of the electric fluid, and to which electricians do not ſeem to give a ſufficient attention.

1. The electric fluid exiſts in all ſubſtances, in a certain quantity, which is natural to them.

2. The electric fluid is repulſive of itſelf, that is to ſay, each particle of electric fluid tends to recede as far from another particle of the ſame fluid as it can.

3. The ſtate of electricity of a body is that in which it has acquired more electrical fluid than the neighbouring bodies, or in which it has leſs of this fluid than the ſurrounding bodies.

4. In the firſt caſe the electrical fluid tends to expand itſelf through all bodies near it, which can by their nature receive it. In the ſecond caſe, the electrical fluid of all the ſurrounding bodies finding leſs reſiſtance towards a body

a body negatively electrified, or having loſt a part of its natural ſhare of electricity, ruſhes towards that body, and tends to diffuſe itſelf through it, and thus to diſpoſe itſelf into an equilibrium.

5. The reaſon why the electric fluid, exiſting every where, ſeems to remain inactive in the common ſtate of nature is, becauſe all other bodies having their ordinary ſhare of this fluid, an equal preſſure exiſts on all ſides. Thus, if all the bodies upon the earth were to acquire more or leſs of electric fluid at the ſame time, in equal proportions, no electrical phenomena would be the conſequence of ſuch a ſtate; becauſe the preſſure being every where equal, the repulſive force of the electrical particles would be every where balanced. Thus two bodies, both negatively or both poſitively electrified, will not give a ſpark to one another: they only recede more from one another, becauſe the other ſurrounding bodies are not in the ſame ſituation with them. This aſſertion ſeems to be illuſtrated by Father BECCARIA's electrical well *(puteus electricus)*, which is nothing but a metal veſſel electrified, in which two cork balls are ſuſpended by ſilk threads; the balls do not ſhow ſigns of electricity within the cavity of the veſſel, becauſe the electric fluid preſſes equally on every ſide.

6. All non-conducting bodies may acquire on each part of their ſubſtance more or leſs of the electric fluid, as well as conducting bodies, at leaſt to a certain proportion; but they do not allow it to paſs freely through their ſubſtance or over their ſurfaces.

7. All bodies whatſoever are ſuſceptible of electricity, poſitive and negative indifferently, either by exciting them by friction or any other way, or by bringing them within the ſphere of action of a body already electrical; ſo that even metals, the beſt conductors, may be as eaſily excited by friction, if inſulated, as glaſs or ſealing wax. The only material difference between the conducting and non-conducting ſubſtances ſeems to be, that the electricity does not ſpread itſelf ſo eaſily and ſo rapidly through or upon thoſe bodies which are non-conductors as upon thoſe which are conductors. An electrical ſpark thrown upon the ſurface of a piece of metal inſulated, of whatever length it be, diffuſes itſelf equally through the whole maſs, if this metal be left to itſelf out of the ſphere of action of another body charged with electricity. The whole electricity communicated by this ſpark is diſcharged at once by touching any part of the ſame metal. On the contrary, electricity ſeems rather to ſtick to that part of a non-conducting body to which it is applied, ſpreading but ſlowly and unequally over its ſurface, from

which it may be taken by degrees, by touching thoſe parts to which it was applied. There are ſome bodies which ſeem to be of a middle ſtate between theſe two, *viz.* through which the electric fluid propagates as through good conductors, but ſlowly, ſuch as common wood, moiſt air, and many other bodies. Electricity ſeems to diffuſe itſelf through theſe bodies almoſt as ſugar and ſalt diffuſe themſelves through water, ſpreading farther and farther through the liquid.

8. All thoſe bodies, which are non-conductors, ſeem to acquire a ſtate of electricity with ſome reluctance; and, after they have acquired it, to hold it more tenaciouſly, or to part with it with more difficulty, than conductors. One touch takes away all the electricity of a metallic body, but does not abſolutely convey away all the electricity of a piece of glaſs or another electric body, ſuch as ſealing wax, amber, &c. The metal plate of an electrophore takes almoſt no electricity at all from the reſinous cake, if it be lifted up without having been touched when it was upon the cake.

9. All reſinous bodies, ſilk and many others, retain more tenaciouſly their ſtate of electricity than glaſs, however dry. Thus a piece of glaſs excited is almoſt quite deprived of its electricity by a conducting ſubſtance

being applied to it; but a reſinous body, though touched, retains ſtill a great ſhare of its electricity.

10. A conducting body inſulated, being placed within the ſphere of action of an excited non-conducting body, or even in contact with it, acquires at the ſame time two contrary electricities; *viz.* the part in contact, or very near the non-conducting electrified body, acquires a contrary electricity to that of the non-conducting body, at the ſame time that the oppoſite or farthermoſt extremity is poſſeſſed of the ſame electricity with the conducting body.

11. A conducting body inſulated, being in contact with another conducting body excited with either electricity, acquires the ſame electricity throughout its whole extenſion, or divides with this body its electricity equally.

12. But an inſulated conducting body, being only in the ſphere of action of another electrified conducting body, acquires, as in the firſt mentioned caſe, two different electricities at the ſame time; *viz.* towards the electrified body it acquires a contrary electricity, and at the oppoſite extremity it acquires the ſame kind of electricity with the electrified body.

It ſeems therefore to be a law of nature, that the electric fluid which is accumulated upon a body, and finds an obſtruction in its free paſſage to another neighbouring body by the interpoſition of a non-conducting body (ſuch as dry air, glaſs, &c.) forces by its repulſive power the electric fluid naturally contained in all bodies to the furthermoſt extremity of the neighbouring body, ſo as to excite in its neareſt extremity a kind of defect of the electric fluid, or a kind of vacuum, till at laſt the accumulation of the electric fluid becomes ſo great upon the electrified body, that it overpowers the reſiſtance of the intermediate non-conducting ſubſtance, forces its way through it, and ruſhes in the form of a ſpark upon the neighbouring body.

If the electric fluid be thrown upon the ſurface of a pane of glaſs, coated on both ſides with a metallic ſubſtance, ſuch as tin-foil; the fluid, finding an obſtruction to its paſſage through the body, is crouded upon that ſurface of the glaſs which has received it; forces the electric fluid out of the other ſurface, if ſome conducting body is near it, or in contact with it, and can convey it away; till this fluid becomes ſo much crouded upon that ſurface as to overpower the reſiſtance of the glaſs, and to force its way through the ſubſtance of the glaſs, in order to diffuſe itſelf upon the other ſurface, upon which was produced a kind of vacuum. The glaſs being thus rent is no longer able to be what is called charged; but after the crouded electrical fluid of a prime conductor has in the ſame manner rent the plate of air (which obſtructed to a certain degree its free paſſage between the prime conductor and the neighbouring body) by giving it a ſpark, the ſame ſpark may be repeated at pleaſure, becauſe the opening formed by the ſpark through the plate of air is immediately ſhut up again according to the nature of all fluids.

If an inſulated conducting body be ſituated in the manner deſcribed, ſo as to poſſeſs at its different extremities a contrary electricity, it may impart to any other body brought in contact with it, or within its ſtriking diſtance, a ſhare of that electricity which it has acquired at its farthermoſt extremity. The former body, ſo touched, has effectually loſt that part of electrical fluid which was in a certain manner crouded upon that extremity; and therefore being taken out of the ſphere of action of the excited body, as, for inſtance, a prime conductor, after having thus loſt a part of the electric fluid crouded upon its extremity, is found to poſſeſs a negative electricity if the excited body had a poſitive, and a poſitive if the excited body had a negative one.

Thus we ſee how far we muſt believe what is commonly affirmed as a fact, that a body, plunged in the atmoſphere of an electrified body, acquires a ſtate of electricity contrary to that of the electrified body. If the body plunged in this atmoſphere be of a ſmall extent, it will be found ſo to all appearance, becauſe the two extremities of a ſmall body cannot be ſeparately examined; whereas a body of a certain extent exhibits in a very perceptible manner the two diſtinct electricities. The reaſon of this wonderful phenomenon is to be underſtood by the principles adopted, and may without much attention be underſtood, if we ſuppoſe the excited body to be in a poſitive ſtate of electricity; for in this caſe the atmoſphere of electric fluid ſurrounding the excited body forces by its repulſive quality the electric fluid of the neighbouring body towards its farthermoſt extremity, and thus accumulates or crouds it upon that extremity, from which extremity it is therefore ready to fly off upon any other body, which is of a nature to receive it, being brought near enough.

If the excited body be in a ſtate of negative electricity, the explanation is not ſo obvious as in the poſitive caſe: it requires ſome more attention to conceive what paſſes. The excited body, having loſt a part of its natural ſhare of electric fluid, a kind of vacuum, if I may call it ſo, takes place upon this body. The electric fluid of any other body being in its natural ſtate, and therefore in a kind of inactivity, confined as it were within its limits by the electric fluid of all the ſurrounding bodies, is ſet at liberty, exerts its natural repulſive quality towards that body, upon which it does not find a ſimilar quantity of electric fluid reſiſting its ſpring, or its elaſtic and repulſive quality; it therefore ruſhes towards that kind of vacuum which exiſts upon a body negatively electrified; and thus the electric fluid of this body, loſing its natural ſtate of equilibrium, and accumulating itſelf towards the vacuum, produces there a real poſitive electricity, at the ſame time that the oppoſite extremity has a negative one.

Before I go farther, I muſt ſpeak one word more of that particular quality of conducting bodies, by which they receive, with a kind of reluctance, either ſtate of electricity; and, after having received it, part with the ſame with as much ſeeming difficulty. This quality, not unknown to attentive electricians, who muſt have obſerved it, has commonly appeared ſomewhat extraordinary and difficult to be believed by many electricians, to whom I have happened to explain my theory of the electrophore. As this quality is the foundation of this theory, I conceive it will not be amiſs to demonſtrate it by facts.

The firſt part of this inherent quality of non-conducting bodies, receiving a ſtate of electricity with more difficulty than conducting bodies, is eaſily ſhewn by the following ſimple experiment: a piece of dry glaſs, held near a prime conductor, will receive no electricity, or almoſt none, at the ſame diſtance as that at which a piece of metal or another conducting ſubſtance will have received a conſiderable degree of electricity, or even a full ſpark.

The ſecond part of this inherent quality may be thus demonſtrated: a piece of metal inſulated, as, for inſtance, the metal plate of an electrophore, placed upon the cake of reſin excited with a conſiderable degree of electricity, will not receive any electricity at all, or only a faint one, when it is ſeparated from the cake without having been touched when it was in contact with the cake, or in the ſphere of action of the cake, though it was really in a ſtate of actual electricity all the time it was upon the plate. Now, if the cake of reſin did part as eaſily with its ſtate of electricity as the metal plate, it would leave a conſiderable degree of electricity upon the metal plate; the more as it is well known that the metal does not at all reſiſt the receiving of it.

Though it would be perhaps in vain to attempt a farther explanation of this inherent quality of non-conducting bodies, yet it will be eaſy to illuſtrate this law of nature by an example of another inherent quality in all matter, which Sir ISAAC NEWTON calls the *vis inertiæ*; and is a *vis inſita*, by which matter reſiſts being put in motion, and when it is once put in motion requires as much force to ſtop its motion as it required to be brought from a ſtate of reſt to that of motion.

Let us now conſider attentively the ſtate of a body ſituated, as I have before deſcribed, in the ſphere of action of an excited electric; as, for inſtance, a cake of reſin, a flat glaſs, or any other non-conducting ſubſtance; or, in other words, let us conſider the ſtate of the metal plate placed upon the reſinous cake of an electrophore, ſuppoſing this cake to be excited with a poſitive electricity; which electricity it acquires eaſily by ſliding the knob of a Leyden phial, charged in the common way, over its ſurface and by various other ways. The ſuper-abundant electric fluid of the cake repels the electric fluid of the metal plate to its farthermoſt extremity, and excites there an accumulation of that fluid; or, in other words, produces there a poſitive electricity, whilſt it produces a negative electricity at the ſurface in contact with the cake.

If in this condition a conducting body be brought in contact with the metal plate, or within its ſtriking diſtance, it receives a ſpark from it; which ſpark is the eletric fluid of the metal plate crouded upon the extremity of the metal by the repulſive force of the ſuper-abundant electric fluid of the cake.

If the metal plate be touched at that ſide where it is really in a negative ſtate, it will, notwithſtanding, part with its accumulated poſitive electricity; becauſe the repulſive power of the atmoſphere of the cake will force this crouded electric fluid out of whatever part of the metal is touched, the electric fluid paſſing through metals very freely.

The metal plate, thus deprived of the electric fluid crouded upon it, becomes in a negative ſtate; but the repellent power of the electric fluid of the cake continuing to act upon the metal plate, forces what remains in it towards the farthermoſt extremity, ſo as to produce much the ſame ſtate as it had before it was put upon the cake; ſo that the negative ſtate, in which it is in reality, cannot appear but when this metal is taken out of the preſſing action of the atmoſphere of the cake; and therefore the metal plate being removed, by the inſulating handle, from the cake, gives evident ſigns of having loſt a part of its natural ſhare of electric fluid; or, in other words, of being electrified negatively, the reſinous cake being more tenacious of the ſtate of electricity, which it had acquired, than the metal plate.

If the reſinous cake be in a ſtate of negative electricity, (which it acquires by a friction either with a dry hand, a piece of leather, or a rough ſkin; or by ſliding the negative part of a charged phial upon it, or by many other ways) the contrary muſt happen, *viz.* the electric fluid of the metal plate, finding a kind of vacuum upon the reſin cake, ruſhes upon it, and thus leaves its oppoſite extremity in a negative ſtate.

A conducting body, having its natural quantity of electric fluid, being brought near this metal plate, gives it a ſpark, which ſpark the metal plate retains as an additional quantity. If the metal plate be afterwards ſeparated from the cake, it muſt retain this additional quantity which it has received from the approaching body; becauſe the reſinous cake being, from its nature, more tenacious of the ſtate of electricity acquired than the metal, remains thereabout in the ſame condition as it was before the metal plate was placed upon it; but the metal plate, having acquired an additional quantity in the time it was placed upon the cake, carries with it this quantity, and muſt therefore return from the cake in a poſitive ſtate.

This confirms what I ſaid before, that in the firſt caſe the cake of reſin does not quit readily the electric fluid which it had acquired; and, in the ſecond caſe, does not ſteal from the metal plate the electric fluid which it had loſt.

What happens to the metal plate placed upon the reſinous cake happens alſo to the metal upon which the reſinous cake is commonly fixed; but the reverſe muſt take place, that is to ſay, when the upper plate is taken off the cake in a poſitive ſtate, the metal under the cake muſt be found in a negative ſtate, if the electrophore be placed upon an electrical ſtand.

It may be aſked, what difference there is between an electrophore and a coated phial, or a flat glaſs coated on both ſides and charged? I anſwer, that there is none at all, if both or only one of the metallic coatings can be taken off by ſilk ſtrings, a piece of ſealing wax, or any other inſulating ſubſtance. The very ſame day I received the electrophore ſent to me by his Royal Highneſs the Archduke FERDINAND from Milan (which electrophore was a thin reſinous cake ſtuck upon a flat piece of metal, to which was adapted a metal plate furniſhed with a glaſs handle to lift it up) I produced the ſame appearance by a common pane of glaſs and the metal plate of the electrophore; but ſoon finding that glaſs, however dry, quickly loſes its electricity (probably from its eaſily attracting moiſture from the air) I tried to cover it with a reſinous ſubſtance, or to varniſh it over with a hard copal varniſh; by which means it was eaſily excited by friction, and retained a long while the electrical power, though not ſo long as the reſinous cake.

I will now explain the nature of an electrophore in a manner more familiar to electricians, who underſtand the received theory, by taking inſtead of an electrophore only a common pane of glaſs, adapted as a magical picture, with this difference only, that both coatings may be taken off by ſilk ſtrings faſtened to them, or by pieces of ſealing wax. Having eſtabliſhed a free communication between the common ſtock and the under coating, apply the upper coating to the prime conductor of an ordinary electrical machine, the pane of glaſs is charged in the common way. The prime conductor has forced a ſuper-abundant quantity of electric fluid upon the ſurface next to it, by means of the coating, and as much is forced out of the oppoſite ſurface, and driven into the common ſtock. Open a metallic communication between the two coatings, and inſtantly the glaſs will be, as we call it, diſcharged: and, indeed, it is ſo to all appearance; but, if we examine more accurately what has happened, we ſhall find, that the upper metallic coating has parted, by the diſcharge, with all the electric fluid which the prime conductor had forced upon it, and even with that part of its own electric fluid which the repellent power of the ſuper-abundant electric fluid, communicated to that ſurface of the glaſs by the force of charging, had driven into it; and that the under coating has recovered as much as the glaſs had forced through it into the common ſtock, and has above that acquired or abſorbed that additional quantity which that ſurface of the glaſs, being brought into a negative ſtate, had drawn from the metal itſelf. And thus it will appear, that the glaſs had, in the diſcharging, by no means parted with that ſtate of electricity which it had acquired by the force of charging.

Now, glaſs and all electric ſubſtances receiving with more difficulty a ſtate of electricity, and parting with it with more reluctance, the conſequence muſt be, that, when the two coatings are ſeparated from the glaſs, ſo as not to be in the way of abſorbing or loſing the electric fluid by other conducting bodies being near them, the upper coating, which was poſitive when the glaſs was charged, and nearly in its natural ſtate, when after the diſcharge it remained in conjunction with the glaſs, muſt now give ſigns of a negative electricity, having loſt by the diſcharge a ſhare of even its natural electric fluid in the manner mentioned. The under coating, which was in a negative ſtate when the glaſs was charged, and (like the other coating) in a natural ſtate when after the diſcharge it remained in conjunction with the glaſs, muſt now, being ſeparated from the glaſs, be in a poſitive ſtate, becauſe it had abſorbed a quantity of electric fluid in the manner explained; which ſuper-abundant quantity it muſt take with it in the moment of ſeparation from the glaſs, becauſe the glaſs being unwilling eaſily to change its acquired ſtate of electricity leaves the metal without robbing it of that quantity of fluid which it had acquired.

If theſe two coatings, ſeparated from the glaſs, are brought near one another, they attract each other; a ſpark enſues, becauſe the coating, which has acquired a ſuper-abundant quantity of electric fluid, imparts it to the other, which had loſt as much; and thus a perfect equilibrium is reſtored between them.

If both theſe coatings are applied as before upon the ſame glaſs, a poſitive ſpark may be obtained from the uppermoſt coating, and a negative one from the other. If they are ſeparated again from the glaſs, as in the firſt caſe, the uppermoſt coating will afford a negative ſpark, and the undermoſt a poſitive; and theſe alternate ſparks may be continued a very long while.

This explanation or theory agrees perfectly with the experiments exhibited by our deceaſed member, the late Mr. CANTON, with elder pith balls hanging by linen threads from a wooden box, which balls are excited either negatively or poſitively by a piece of excited glaſs.

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